Comminutors are employed to reduce the size of particles to a range which is desirable and to liberate impurities so that they can be removed downstream of comminution. The feed particles may range in size up to several inches while the product particles may range from inches down to microns in size. More comminution energy is required to bring a mixture of particles of widely ranging friabilities to the desired size consist than when the friable components alone are present. The invention relates to reducing comminution energy consumption and increasing the throughput of comminutors while improving the quality of the product of comminution by separating the friable and less friable components as they are liberated from the feed matrix within the grinding operation and before the hard component is overground. Specifically, the invention relates to modification and operation of comminuting devices and their classifiers, if they are used, so as to separate two streams from the comminution device. One is concentrated in the hard and less friable components liberated from the feed in the grinding operation. This may be either an impurity or a valuable component of the feed. The other is concentrated in the friable component of the feed. More specifically, the invention relates to combining the operation of a comminution device and a separation device so as to separate the hard components of the feed as they are liberated inside the comminutor but before they are overground. Separation methods based on gravity, size classification, dry magnetic separation, and triboelectric means are used to separate hard material [form] <u>from</u> friable material found in a mill concentrated steam taken from the comminution device. Particulate matter of differing chemical and physical makeup can have

different magnetic properties and may be electrically charged by contact and friction, tribocharging. By including triboelectric separation means, modified dry magnetic separators can be effective in recovering friable material of a great range of types from the mill concentrated fraction taken from the mill. By this combined pulverizer-separator operation, the MagMill™ can produce high quality comminution products without significant loss of the desired component. The MagMill™ is the name given to the above described combination of mill and separator. The friable material so separated is returned to the grinding zone for grinding to product fineness while the hard component is collected separately and not returned to the mill. By this means, both the quality and the recovery of the separated components are improved when compared to that of the state-of-the-art technology in which everything is reduced to the same size consist and then separated downstream of the comminution device.

Page 5, line 15-page 6, line 17:

The logical place for fine coal cleaning is in the pulverizers, which are already used by the power plant. Indeed, EXPORTech Company, Inc. (Y. Feng, R.R. Oder, R.W. DeSollar, E.A Stephens, Jr., G.F. Teacher and T.L. Banfield, "Dry Coal Cleaning in a MagMill™, appearing in the Proceedings of the 22nd International Technical Conference on Coal Utilization and Fuel Systems," Clearwater, FL, March 16-19, 1997; See also R.R. Oder, R.E. Jamison, and E.D. Brandner, "Preliminary Results of Pre-Combustion Removal of

Mercury, Arsenic, and Selenium from Coal by Dry Magnetic Separation," appearing in the Proceedings of the 24th International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, FL, March 8-11, 1999, pp. 151-158, incorporated by reference herein) has shown that refuse with high levels of ash and sulfur can be separated from the internal circulation of almost all commercial pulverizers used at power plants and that removal of this refuse from the mill can lower the ash and sulfur levels and reduce the levels of toxic trace elements in the pulverized product. ETCi has further demonstrated that dry magnetic separation can be used to recover clean coal from the refuse (R.R. Oder, R.E. Jamison, and J.R. Davis, "Coal Cleaning at Pulverized-Coal Fired Power Plants," Proc. 11th Annual Pittsburgh Coal Conference - Coal: Energy and the Environment, Sept. 12-16, 1994, Pittsburgh, PA, Ed., S-H Chiang, pp. 640-645 (1994), incorporated by reference herein). Additionally, ETCi has suggested that the combined process of pulverization, size and density classification in the mill, dry magnetic separation for recovery of clean coal from the mill refuse, plus return of the clean coal to the pulverizer for grinding to product fineness, is a novel method for efficient separation of ash forming minerals, sulfur, and hazardous pollutants from the coal fed to a pulverized-coal fired power plant. This novel method is not practiced in the electric power industry because of the significant engineering challenge associated with removal of a concentrated stream of refuse from the pulverizers. This obstacle has now been overcome and is the basis for the invention disclosed here.

Page 6, line 18-page 7, line 11:

It is important to note that others have used magnetic separation to separate hard gauge material from the feed to pulverizers, which is standard practice in the industry, and some also to recover the value component from the underflow in the pyrite traps or tramp metal chutes employed in most grinding mills. While this material may be blended with the product or returned to the mill for further grinding, these efforts have treated only a small amount of the material fed to the mill. The current invention is greatly different from these past efforts in two major ways. First, large amounts of material are extracted from the internal circulation of the mill from locations other than the tramp iron chutes. Secondly, powerful magnetic separation techniques are employed which have the capability for separation of materials ranging from strongly magnetic to diamagnetic. Indeed, with the addition of triboelectric phenomena (ElectriMag™ Separator co-pending application having Serial Number 09/289,929 filed on April 14, 1999, incorporated by reference herein), the method is now capable of separating particles based on both magnetic and surface charging characteristics. The ElectriMag™ separator is the name given to a separator which combines magnetic and electric forces where the electric charge is imparted by friction and can be different for particles of different physical and chemical characteristics especially surface charging characteristics. The present invention goes far beyond the present state-of-the-art. For this reason, the technology is not restricted to conventional applications to separation of strongly

magnetic particles from inert materials. With the combined action of the pulverizer to liberate on the basis of differences in friability and the electric/magnetic separation mechanism employed, the technology can be applied to a wide range of important new applications.

Page 17, line 9:

Sub B2

The grinding chamber **200** inside of the pulverizer is shown in more detail in Figure **2**. In the figure, **201** is a heavy stationary grinding ring. **202** is a rotating roller. The roller is [suspended **203** from] attached to shaft **203** that is supported by a rotating crossbar **204** cantilevered from a vertical centered drive shaft **205**. Particles are pulverized by compression between the grinding ring **201** and the rotating rollers **202**. One roller, **202**, is shown in Figure **2**. Mills may employ several rollers. A rotating plow, **206**, cantilevered from the center shaft, throws the large, heavy particles which land near the center of the mill base back into the grinding zone between ring and rollers. Particles which are difficult to grind and which are too heavy to be lifted by the air flow, **5**, entering the mill base through air flow casing **18** and passing through a plurality of vanes **208** concentrate in the base of the pulverizer **207**. Removal mechanism **7** passes through the air scroll casing **18**. It opens to the base of the mill inside one the air flow vanes **208**. A second removal mechanism **8** enters the grinding chamber at **209** above the elevation of the rotating cross bar **204**.

Page 18, line 1:

Hot air **5** is blown into the base of the mill **207** through the air casing **18** shown in Figure **3.** Temperatures up to 250 to 350 degrees Fahrenheit can be used. The air is heated upstream of the air scroll casing by means not shown. The air enters the base of the mill with velocities ranging upward to several thousand feet per minute. The air swirls around the casing and enters the mill through vanes **208** opening underneath the grinding ring **201**. The vanes direct the air flow tangential to the inside diameter of the grinding chamber **200**. Removal mechanism **7** opens to the mill base in the grinding chamber through vane at **208.** It is a screw conveyor of the type manufactured by AFC of Clifton, NJ. The separation mechanism may be located in any air inlet vane around the circumference of the pulverizer but preferentially is located away from the pulverizer inlet **4**. The screw conveyor opens just inside the vane without protruding into the base where it would be hit by the plow. The air flow slot **301** immediately upstream of the screw conveyor opening is plugged off to prevent air flow. In operation, this permits buildup of particles in front of the screw conveyor. It is not necessary to employ an air lock device at the exit of the conveyor because air flow is blocked by particles inside the length of the conveyor. The screw conveyor mechanism must be able to operate at the temperature in the base of the pulverizer. More than one removal mechanism **7** may be used in the base of the mill.

Page 18, line 25:

The inside of the pulverizer at an elevation above the top of the gear train mechanism **211** is shown in Figure **4**. The casing **400** encloses the inverted cone of a static classifier **401**. Air and particles passing upward through the mill enter the classifier through vanes **402**. Small particles and air exit the pulverizer through the product pipe at **6**. Oversize particles drop to the bottom of the inverted cone and return to the grinding chamber **200** through flap valves **403**. A removal mechanism **9** is attached to the outside wall of the casing **400**. It connects to the inside space between the casing wall and the inverted cone **401**. A removal mechanism **10** passes through the casing **400** and is attached to the bottom of the inverted cone at the flap valves **403**.

Page 19, line 9:

Removal mechanism **8** is a kick-out door. It opens to the inside of the pulverizer chamber at **209**. The removal mechanism **8** can be located at any elevation from the top of the roller **202** up to the top of the grinding chamber at **210**. ~~It is~~ preferentially at an elevation above or below the rotating arm **204** and at a location around the circumference of the grinding chamber which is away from the feed **4** and the mill drive shaft **212**. More than one removal mechanism **8** may be used in the grinding chamber.

Page 19, line 18:

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Removal mechanism **9** is a kick-out door. It opens into the region of the pulverizer above the top of the gear train mechanism **211** between the casing **400** and the inverted cone **401** of the classifier. It can be located at any elevation from the top of the gear train mechanism **211** up to an elevation below the entrance to the classifier at **402**. More than one removal mechanism **9** may be used above the top of the gear train mechanism. It can be located anywhere around the circumference of the classifier.

Page 20, line 24:

a9

A second mechanism **600** for removing particles from the inside of the pulverizer is shown in side view in Figure **6**. The mechanism is mounted to the side of the pulverizer **601** through explosion proof gate valve **500**. The sampling device consists of a rectangular chamber **604** which is mounted to a flange **602** for attachment to the gate valve on the side of the pulverizer. The flange makes an angle of approximately 60 degrees with respect to the vertical. The gate valve **500** can be attached directly to the side of the pulverizer or can be attached to access doors on the side of the pulverizer using a transition plate **603**. The transition plate is a plate which is thick enough to withstand 50 psi excursions in the pressure and which is used to accommodate the difference in the bolt hole locations on

the gate valve **500** and those on the pulverizer. The chamber **604** contains a sampling device **605** which is rectangular in cross section and which is open at end **606** and has an opening in one wall at the other end **607** as shown in the Figure. A rod **608** is attached to the inside face of the sampling chamber at **613**. This rod passes through the vertical wall at the back of the sampling mechanism at **609**. A dustless connector **610** consisting of a cylindrical hollow fibrous plug surrounding the rod **608** and fitting inside a cylindrical sleeve **614** prevents dust leakage from the inside of the pulverizer. The rod **608** is used to move the sampling device **605** into and out of the pulverizer. The sampling device can be arranged to open up, as shown in Figure **6**, or to open down. Adapter **611** connects the sampling device **600** to an air lock mechanism **705** for isolating the material being taken from the mill.

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Page 21, line 24:

Particles removed from the pulverizer by removal devices **7, 8, 9, or 10** can be issued to reject stream **17** directly or conveyed **11** to feed hopper **20.** The particles withdrawn from the internal circulation in the mill by any of the sampling mechanisms, **7, 8, 9,** or **10** can be directed individually or in combinations to the reject stream **17**. The conveyance mechanism **11** can be a screw conveyor or a conventional conveyor of the type manufactured by AFC of Clifton, NJ. The conveyance mechanism **11** and the separation mechanism **2** and return conveyance mechanism **16** and the reject conveyance mechanism **17** should be enclosed

a10

to prevent dusting. The capacity of the conveyors **11** ranges from 1/10 to the full rate at which particles are fed to the pulverizer and preferentially is in the range of 1/3 to ½ of the full rate of the feed. The capacity of the return conveyance devices **16** and the reject conveyance mechanism **17** ranges from 1/6 to the full rate of the feed to the pulverizer.

Page 22, line 20:

The following description refers to Figure **8.** Particles in the size range from .07 mm to 3 mm discharge onto a vibratory feeder **100** of the type which can be obtained from Eriez Magnetics, Erie, PA, such as Model No. 15A. The surface of the vibratory feeder **100** is made of a conducting material which has a work function which is intermediate between those of the particles to be separated. The work function of a material is "the minimum energy required to remove and electron from the interior of a solid to a point just outside the surface" (CRC Handbook of Chemistry and Physics, 81st edition, Edited by David R. Lide, CRC Press LLC, Boca Raton, Florida, 2000, Page 2-59, incorporated by reference herein). For example, in sorting coal particles containing mineral impurities copper may be used. The vibrating tray serves as a means to triboelectrically charge the particles and to move them to the surface of a belt conveyor **801**. Particles with the lowest work function will generally become positively charged and the particles with greatest work functions will become negatively charged. The particles pass under a permanent magnet **802** as they fall onto the

belt. The permanent magnet serves to remove strongly magnetic gangue material such as shards of iron which may be in the mixture of particles. The particles are further charged by sliding friction as they fall onto moving belt **801**. The belt carries the particles to the magnetic pulley **803** at the end of the belt conveyor. The belt can be made from insulating, or conduction material and can have iron fibers implanted in the surface to enhance the magnetic field gradient at the surface of the magnetic separator **803**. Preferably the belt is made from antistatic material such as can be purchased from Taconic, Petersburgh, NY.

Page 24, line 3:

a12

Particles which migrate to the regions of high magnetic flux such as **906** and **907** and which are held there by magnetic forces at the surface of the belt are carried around the axis **908** of the pulley **803** by the belt **801** and drop free from underneath the belt at **804** as the belt pulls away from the cylindrical magnet surface. A brush **807** is located at the back edge of the idler pulley **808** to remove particles adhering to the belt.

Page 34, line 9:

a13

Particles withdrawn from the pulverizer by mechanisms **2101** can be either issued to reject stream **17** directly or conveyed **11** to separation mechanism **2** as shown in

Figure **1**. The separation mechanism used here is exactly the same as that discussed above for the case of the ring/roller mill. The particles to be returned to the pulverizer from separation mechanism **2** can be returned through the wall of the pulverizer at **2198** or preferably through the feed chute **2111.** An air lock mechanism **705** of Figure **6** or **705** of Figure **7** is employed to isolate the atmosphere inside the mill from that in the separation mechanism **2**. Reject particles are discharged from the pulverizer and separation mechanism into stream **17** of Figure **1**.

Page 37, line 5:

Particles withdrawn from the pulverizer by mechanisms **2201 and 2299** can be conveyed directly to reject stream **17** or conveyed **11** to separation mechanism **2** as shown in Figure **1**. The separation mechanism used here is exactly the same as that discussed above for the case of the ring/roller mill. The particles to be returned to the pulverizer from separation mechanism **2** can be returned through the wall of the pulverizer at **2298** or preferably through the feed chute **2211.** An air lock mechanism **705** of Figure **6** or **705** of Figure **7** is employed to isolate the atmosphere inside the mill from that in the separation mechanism **2**. Reject particles are discharged from the pulverizer and separation mechanism into stream **17** of Figure **1**.

a14

Page 38, line 15:

A portion of the hard particles are withdrawn from the mill by particle sampling mechanisms **7, 8, 9, and 10.** Some types of conventional pulverizers such as roller mills separate large and very hard debris such as iron spikes from the grinding zone through openings in the air flow passages in the bottom of the pulverizer (not shown here). These openings are generally called pyrite traps. They remove a very small amount of material from the pulverizer, generally less than 0.1% of the feed. The pyrite traps are intended to protect the pulverizer from damage. They are not used to improve the quality of the product of pulverizing. In a MagMill™, material is removed from the inside of the pulverizer through sampling mechanisms **7, 8, 9, and 10** at a very high rate. This can be as much as 100% of the rate at which particles enter the mill. Preferably, it is between 10% and 100% of the feed rate. More preferably it is between 30% and 50% of the feed rate. The purpose of removing this material is to improve the quality of the product. The advantage of processing this stream of particles taken from the internal circulation of the pulverizer is the extra mineral liberation in this stream. The particles are intermediate in size between the size of particles fed to the pulverizer and that issued in the product. Separation of particles in this stream is more efficient than treating the feed. Further, this stream of particles has a high concentration of the hard material to be removed so that the separation mechanism **2** can be smaller than that required to

treat the entire stream. The MagMill™ is a technically and economically advantageous method for improving the quality of the pulverizer product.

Page 39, line 11:

Particles which are removed from the internal circulation of the pulverizer through sampling mechanisms **7, 8, 9, and 10** can be either issued to reject stream **17** directly or fed to the hopper **20** and screening device **12** where oversize particles **15** are withdrawn. The particles withdrawn from the internal circulation in the mill by any of the sampling mechanisms **7, 8, 9,** or **10** can be directed individually or in combinations to the reject stream **17** when the quality of the particles does not warrant processing through separation mechanism **2**. Oversize particles are those which are too coarse for effective treatment in the separation mechanism **2**. They are generally coarser than 8 mesh or about 3 mm. The top-size is dependent on the characteristics of particles to be processed in the separation mechanism. Generally, strongly magnetic particles can be processed efficiently at a coarser size consist than can feebly magnetic particles such as coal. When grinding coal, pulverizer concentrated particles are generally smaller than 8 mesh with only a few percent finer than 100 mesh. If the oversize particles coarser than 8 mesh are highly concentrated in hard impurity particles, they are rejected to stream **17**. Otherwise the oversize particles are returned to the pulverizer for additional grinding through steam **16**. Under size particles, generally finer than 8 mesh,

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are fed to the electric and magnetic means **2** where particles are separated on the basis of air drag, particle mass, surface charging, and magnetic characteristics. The less desirable hard particles separated by separator **2** are rejected from the MagMill™ in stream **17**. The friable particles recovered by the magnetic separator are returned to the pulverizer for grinding to specification in stream **16**. For coal, separation of mineral gangue results in a pulverized-coal product which has lower concentrations of ash, sulfur, and associated trace metals than the coal fed to the pulverizer.

Page 40, line 12:

G17

The following description of the method is given in terms of pulverizing coal in a ring/roller mill. It illustrates the principles of separation in operation inside the mill and shows the function of the electric and magnetic separator. While the grinding mechanism illustrated is that of a ring/roller mill, mills and crushers of other types could have been used and products coarser than pulverized are possible. Further, the separation mechanism shown is not limiting. Means for particle size classification other than screening such as air classifiers, air tables, air cyclone, etc. can be used. Additionally, in some instances only the first stage ElectriMag™ Separator may be required.

Page 40, line 24:

Figure **17** is a cut-away view of a MagMill™ pulverizer which consists of an air-swept ring/roller pulverizer **1** and a separation means **2** working together. Raw feed **3** consisting of a plurality of particles of widely differing sizes with varying degrees of association enters the pulverizer **1** through the mill housing at **4**. The largest particle is generally ½ inch to 1 inch in size. The feed can enter the mill from the top as well using means not shown. For coal pulverizing, the ash concentration of the feed coal may range from a few percent on a weight basis to 30 to 50 Wt.% or even higher while 7 to 10% is typical. The sulfur content may range from below 1 Wt.% up to 5 or 10 Wt.% or even higher while 1 to 2% is typical. The MagMill™ separates a mineral fraction, iron pyrite, which generally contains 50% of the sulfur in the coal. The concentration of the iron pyrite in the feed to the MagMill™ can range from less than 1 to 5 Wt.% or higher. It is generally in the range from 0.5 to 1% Wt.%. Pre-combustion separation of iron pyrite will lower the sulfur oxide concentration in the combustion products which must be scrubbed and, perhaps more importantly, will reduce the amount of reactive iron sulfides at the water wall when low nitrogen oxide (NO_x) burners are used. Water wall wastage is related to reactive iron sulfides produced when iron pyrite is burned in low NO_x burners. The resulting sulfides migrate to the boiler walls and release sulfur which is very corrosive under the reducing conditions.

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Page 41, line 19:

There are many trace metals in coal. Each can range from parts per billion based on the weight of coal to thousands of parts per million. Of the trace metals, mercury, arsenic, and selenium are of particular interest because they are considered hazardous air pollution precursors (HAPS). Mercury is of particular interest because of the emissions restriction anticipated, less than 1 pound of mercury per 10^{13} Btu or approximately 1 pound of mercury per 10^9 pounds of coal, and the difficult and cost of removal from flue gases, of the order of $20,000 per pound of mercury. With mercury levels typically 100 pounds per billion pounds of coal, very high efficiencies of removal will be required. Arsenic is of additional interest because this trace metal poisons catalytic reactors used for separation of nitrogen oxides from the combustion off gases. Catalyst replacement is very expensive.

Page 43, line 7:

Particles colliding with or moving near the walls of the grinding chamber **200** are removed from the pulverizer through removal mechanism **8** mounted on the wall of the grinding chamber. There may be more than one such removal mechanism and they may be mounted at various elevations above the top of the grinding zone in the base of the mill **207**. The removal mechanism **8** opens into the mill through a hinged door which can be directed to catch particles which are rising, falling, or moving around the circumference of the mill in either clockwise or counterclockwise direction. An air-jet mechanism **615** can be used to

prevent excess amount of fine material from being withdrawn from the mill. This is accomplished by directing the air jet into the mill through the opening for mechanism **8**. The coarse particles which are deflected into the removal mechanism fall through an airlock mechanism which serves to isolate the atmosphere inside the mill. The mill can be of the overpressure or the under-pressure type. Particles exiting mechanism 8 can be discharged to the reject stream **17** directly when the quality of the particles does not warrant processing with separation mechanism **2** or conveyed to the separation mechanism **2** via conveyor **11**. This conveyor can be a screw conveyor, a belt conveyor, elevator or any method for moving the particles in the minus 8 mesh size fraction.

Page 44, line 1:

Particles which are falling along the inside wall of the outside casing of the classifier are removed from the pulverizer circulation by removal mechanism **9**. More than one such mechanism may be employed and they may be mounted at any elevation below the entrance to the classifier at the top of the mill. This mechanism may be arranged to catch particles rising, falling, or with a vortex motion in either direction around the inside wall of the classifier casing. Preferentially, it is arranged to catch particles falling back to the grinding zone. An air jet mechanism **615** similar to that described above can be used to prevent an excess of small particles from exiting the mill. The mechanism and the means to

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convey to the separation mechanism **2** or to the reject stream **2** are similar to that of removal mechanism **8**.

Page 44, line 27:

Particles withdrawn from the pulverizer 1 are conveyed **11.** They can be discharged to the reject stream **17** directly when the quality of the particles does not warrant processing with separation mechanism **2** or to the storage bin **20** at the input to the separation mechanism **2**. Particles are discharged from bin **20** to the size classification means **12** which, for this example, is a screen. The undersize particles, generally smaller than 8 mesh, are discharged to vibratory feeder **100.** The oversize particles **15** can be conveyed either to the pulverizer for additional grinding **16** or conveyed to reject **17** depending upon the quality of the particles. The product of the separation mechanism is returned to the pulverizer **16** for grinding to size specification. The reject from the separation mechanism is conveyed to refuse **17**.

Page 45, line 11:

Referring now to figure 8, the vibratory feeder **100** serves to convey the undersize particles to the belt separator **801** and to electrically charge the particles by friction

and contact. The material surface of the vibratory feeder is preferentially an electrical conductor which has a work function which is intermediate between the two major types of particles to be separated. For coal, copper is preferred. In contact with copper, the hydrocarbon component of coal will lose electrons to the copper and become positively charged. The inorganic particles to be separated will generally acquire the electrons from the copper and become negatively charged. In addition to serving as an intermediary in the transfer of charge, the copper is an electrical conductor and this facilitates the charge transfer. The copper and inorganic particles do not have to be in direct contact to transfer the charge. The particles can also transfer charge by direct contact.

Page 48, line 9:

a4

Negatively charged particles which are the most magnetic will travel around the arc of the first magnetic separator and will leave the belt underneath and away from the separator. They will generally have negative electric charges less than -10^{-5} coulombs/kg and magnetic susceptibilities greater than $10 - 50*10^{-9}$ m^3/kg. They will exit the first separator at **804**.

Page 53, line 4:

Figure 17 and the description which follows it illustrates a preferred embodiment of this invention. It is not restricted to pulverizing coal but can be used to improve the properties of any material for which size reduction will liberate the particle components and for which the size reduction mechanism serves also to concentrate one fraction while the separator mechanism serves to separate one fraction. The air-swept pulverizer used for illustration is of the ring/roller type such as that manufactured by Bradley Pulverizer Company of Allentown, Pennsylvania. While the grinding mechanism employed is that of a ring/roller mill, all other mills for which particles circulating inside the mill can be accessed, such as hammer mills and roller mills, can be used. The classifier oversize material which is returned to the grinding zone from pulverizers such as ball mills can also be treated by the method of this invention. The method described above can be used in pulverizers employing under pressure or over pressure. Further the preferred separator means including size classification and magnetic separation are illustrative of the invention and are not intended to be limiting. Other means of separation can be employed such as size classification alone, or magnetic and electric separation, cyclones, air tables, etc.